EFFECT OF SIGNIFICANT CLIMATIC FACTORS ON AGRICULTURAL PRODUCTION AND INCOMES

A NEW ZEALAND EXAMPLE

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ABSTRACT

Recent studies relating to the human use of the atmosphere have emphasized the need for investigations into the economics of weather and climate. They reveal that little attention has been given by meteorologists to the non-scientific gains of their profession. Of the many gains, those affecting the agricultural community are of primary importance. The technique of assessing the gains associated with monetary variations in agricultural production is examined through the use of an "agroclimatological model" for several agricultural products in New Zealand.

The most significant partial correlations were examined, the subsequent analysis indicating the importance of climatic variations on various aspects of agricultural production, and their effects on agricultural incomes. The major finding of the analysis is the significance of climatic factors in their influence on butterfat production, a "significant" climatic variation such as a "wet" January, for example, being "worth" about $N.Z. 2 million to the dairy farmers in South Auckland—New Zealand's premier dairying area.

1. INTRODUCTION

Considerable emphasis has been directed in recent years toward assessment of the potential effects of *weather modification* on various types of activity. Recent studies relating to the human use of the atmosphere (Sewell [4]) have emphasized, however, that there is an urgent need for investigations into the more basic question of the effect of *weather* on these same activities.

A preliminary effort to assess the nature of economic and related benefits associated with the program of the World Weather Watch has been made by Thompson [5]. His survey of the literature, concerning the economic and other gains which may be expected to accrue from the implementation of the World Weather Watch program, reveals that little attention has been given by meteorologists to the nonscientific gains of their profession.

Of the many gains that should be considered, those affecting the agricultural community are perhaps of primary importance, and the gain or loss of income from agriculture through the effect of climatic variations on agricultural production is of real concern.

Toward this end an attempt is made in this paper to assess the effect of significant climatic variations on agricultural production in New Zealand and its ultimate impact on agricultural incomes. This assessment is made through the use of a regression model described in detail elsewhere (Maunder [1]). Although the model was developed through the investigation of agricultural production in New Zeland, it could be applied with modifications to agriculture in other countries too. The technique of assessing the gains associated with monetary variations in various kinds of activity (in this case agriculture), could also be used to trace the impact of weather changes on other aspects of the economy.

2. METHOD

An "agroclimatological model" (Maunder [2]) was formulated for 18 different agricultural factors and for 27 different areas (mostly counties), based on variations in agricultural production and climate, mainly since the 1930's.

The climate variables available for use in the analysis were the seasonal and monthly data for rainfall, temperature, and sunshine. An assessment of the climatic record showed that 27 stations in New Zealand had suitable records from 1933/34 to 1959/60. This period of 27 seasons was the maximum possible because some of the sunshine data prior to 1933/34 were not reliable, and also because a number of climatic stations had not been established until the early 1930's. Even so, most of the stations still had incomplete records in that changes of site had occurred and in some cases this meant that the full 27 seasons could not be used.

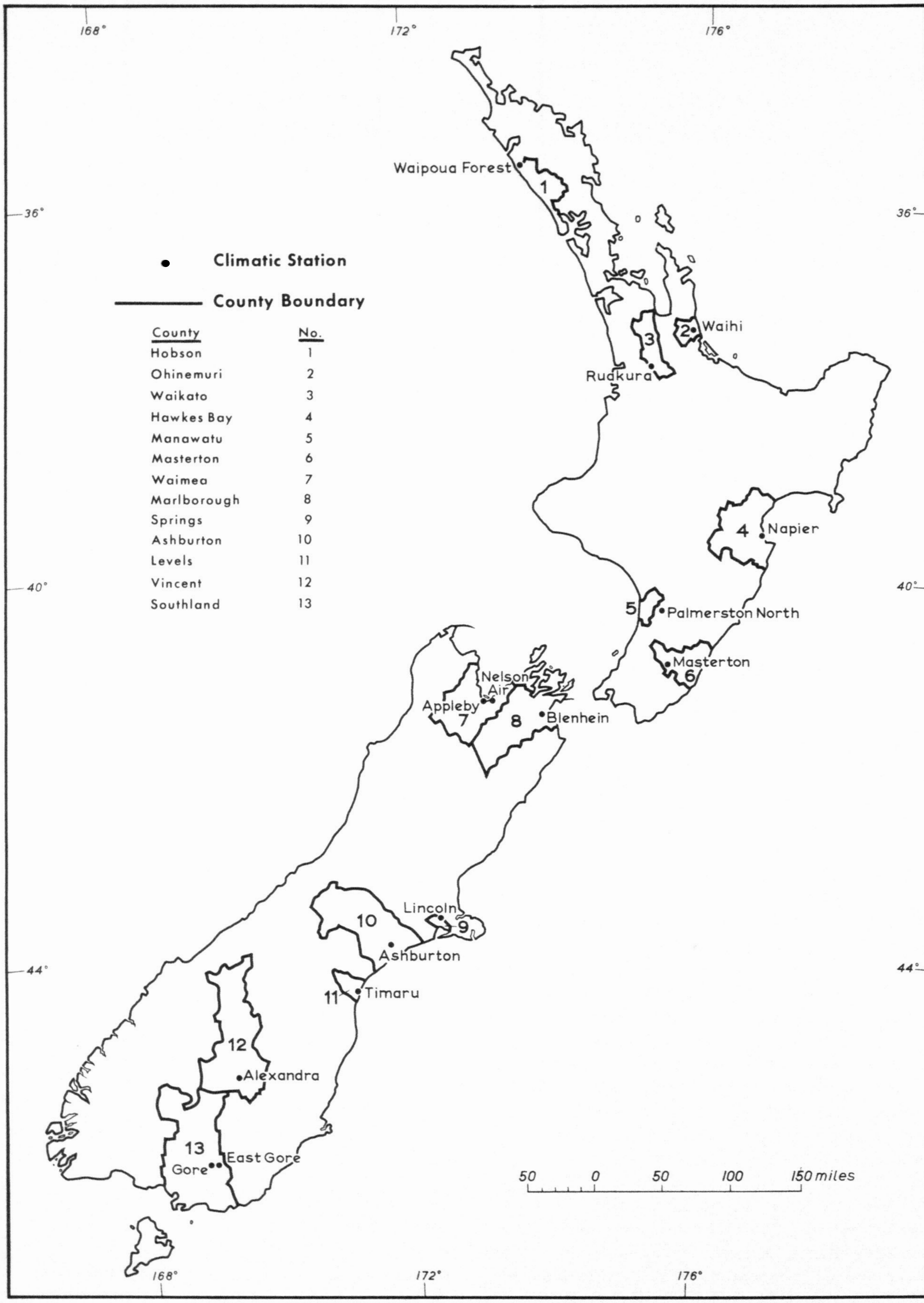

FIGURE 1.—Locati on map: counties and climatological stations.

The climatic records thus available were used in conjunction with the agricultural records for the county within which the climatic station was located or the nearest appropriate county. Accordingly, 27 climatic station-county pairs were available, and the appropriate agricultural data were assessed for each. No data were therefore examined for the other 93 counties in New Zealand. The locations of counties mentioned in this paper (13 of the 27 analyzed) and the paired climatic stations are shown in figure 1.

Analyses were made for each of 18 agricultural factors, these factors being divided into three divisions—crops and butterfat production, wool and meat production, and apple and pear production. Monthly climatic data (the same for each agricultural factor and for each county) were used for crops and butterfat, and seasonal data were used for the other factors (different data for the two divisions). Separate analyses were made for each relevant agricultural factor in each county or area; thus, in the case of wheat production, 16 analyses were made since wheat production was considered to be important in 16 (of the possible 27) counties.

The analyses or agroclimatological models used were in the form of a multiple regression, three different models being used for the three divisions of agricultural factors described above. The relevant equations for these models are shown in table 1. In table 2, a specific example of model I is given for butterfat production as it applied to the Waikato County, center of New Zealand's principal dairying area. The application of the detailed results as given in this table is explained in the following section.

TABLE 1.—*Agricultural factors*

Model I*	Model II**	Model III***
Wheat yield per acre Oat yield per acre Barley yield per acre Potato yield per acre Pea yield per acre Corn yield per acre Onion yield per acre Tobacco yield per acre Butterfat yield per cow	Wool per sheep shorn Wool per acre Meat per acre	Apple production Apple production per tree Pear production Pear production per tree

*$y=a_0+a_1x_1+a_1'x_1^2+a_2x_2+ \ldots +a_{15}x_{15}$
where y=agricultural factor.
x_1=time (season 1933/34=1, 1934/35=2, etc. in most cases).
$x_2, \ldots, x_6$=rainfall: Oct., Nov., Dec., Jan., Feb.
$x_7, \ldots, x_{11}$=mean temperature: Oct., Nov., Dec., Jan., Feb.
$x_{12}, \ldots, x_{15}$=sunshine: Nov., Dec., Jan., Feb.
**$y=a_0+a_1x_1+a_2x_2+ \ldots + a_7x_7$
where y=agricultural factor.
x_1=time (season 1949/50=1, 1951/52=2, etc. in many cases).
x_2, x_3, x_4=rainfall: previous summer, previous autumn, previous winter.
x_5, x_6, x_7=mean temperature: previous summer, previous autumn, previous winter.
***$y=a_0+a_1x_1+a_1'x_1^2+a_2x_2+ \ldots + a_{11}x_{11}$
where y=agricultural factor.
x_1=time (season 1941/42=1, 1942/43=2, etc.).
x_2, x_3, x_4, x_5=rainfall: previous autumn, previous winter, spring, summer.
x_6, x_7, x_8=mean temperature: previous winter, spring, summer.
x_9, x_{10}, x_{11}=sunshine: previous winter, spring, summer.

3. SPECIFIC APPLICATIONS OF MODEL

In order to estimate the "effect" of variations in several aspects of the climate (specifically, rainfall, mean temperature, and sunshine), the measure *specific climatic variation* was formulated, and is defined simply as a variation from the average of one standard deviation. A month was described as "wet," "warm," and "sunny" if the departure from the average rainfall, mean temperature, and sunshine was at least one standard deviation above average, respectively, whereas the terms "dry," "cool," and "cloudy" were applied to months having a similar negative departure from the average. In the Waikato County, for example, a "wet" October had a rainfall of 6.29 in. (4.34+1.95), and a "cloudy" February, a sunshine duration of 158 hr. (186−28). The coefficients in the multiple regression equations associating agricultural production with climatic variations were then used to estimate the "effect" on production of those specific climatic variations found to be significant.

The analysis showed, for example, that mid-spring (October) rainfall variations at the Ruakura climatological station were significantly associated (at the 0.5 percent level) with variations in the butterfat production per cow in the Puketaha herd testing group in the surrounding Waikato County. The coefficient of October rainfall in the regression equation (see table 2) is 4.66 (standard error 1.08), hence the "effect" of a specific climatic variation (1.95 in this case) from the average October rainfall (4.34 in.) is 9 lb. (4.66×1.95) for an October with a rainfall 1.95 in. above average, and −9 lb. (4.66×−1.95) for an October with a rainfall 1.95 in. below average. (The standard error in each case is 2 lb., 1.08×1.95.) It may therefore be suggested that, if all other factors remain constant, a "wet" October (one standard deviation above average) is associated with an "increase" in the Waikato County butterfat yield of 9±2 lb. per cow, whereas a "dry" October (one standard deviation below average) is associated with a corresponding "decrease" in production.

The utilization of such a method enables one to suggest that once in say, 5, 6, or 7 years (assuming a normal distribution of climatic data), production of a specific climatic variation such as a "dry" October would be in the order of x lb. Further, the value or economic significance in terms of agricultural income of such a variation in production, may be assessed by multiplying the per acre or per animal variation by the particular total acreage or total livestock population.

The main criteria for such an assessment of the effect of significant climatic variations in terms of agricultural incomes were the agricultural production for the particular area (the 1961/62 seasonal production being taken as the production index), and the wholesale or farm prices prevailing in 1964. For example, in Waikato County the partial correlation analysis showed that the effect of a "wet" October was to "increase" the butterfat yield per cow by 9±2 lb., and the climatic data at the county climatological station Ruakura for the period 1936/37 to

TABLE 2.—*Specific example of model I* showing the effect of climatic variations on butterfat production in the Waikato County,** and the application of these specific data to evaluate the value of a climatic departure of one standard deviation from the average*

Variable	Climate: Average	Climate: Standard deviation	Coefficient of regression	Standard error of regression coefficient	Significance level: t^2	Significance level: (%)	Significance level: Partial r^2	Climatic effect of one standard deviation on yield/cow (lb.)	Value of climatic effect per cow ($N.Z.)	Value of climatic effect per county ($N.Z.)
Rainfall:										
Oct. (x_2)	4.34 in.	1.95 in.	4.66	1.08	18.7	0.5	0.73	9±2	$2.6±0.6	$260,000±60,000
Nov. (x_3)	3.83 in.	1.67 in.	3.21	1.37	5.5	10	0.44	5±2	$1.4±0.6	$140,000±60,000
Dec. (x_4)	3.37 in.	1.43 in.	6.93	2.42	8.2	2.5	0.54	10±3	$2.8±0.8	$290,000±80,000
Jan. (x_5)	3.01 in.	1.82 in.	5.40	1.35	15.9	1	0.69	10±2	$2.8±0.6	$290,000±60,000
Feb. (x_6)	2.69 in.	1.77 in.	5.24	0.20	68.6	0.05	0.91	9±0.4	$2.6±0.2	$250,000±20,000
Mean temperature:										
Oct. (x_7)	54.6° F.	1.5° F.	0.57	1.33	0.2	70	0.03	------	------	------
Nov. (x_8)	57.8° F.	1.4° F.	−4.15	1.33	9.8	2	0.58	−6±2	−$1.7±0.6	−$170,000±60,000
Dec. (x_9)	60.8° F.	2.1° F.	3.39	1.88	3.2	20	0.32	7±4	$2.0±1.1	$200,000±110,000
Jan. (x_{10})	63.2° F.	2.1° F.	1.07	2.03	0.3	70	0.04	------	------	------
Feb. (x_{11})	64.3° F.	2.4° F.	−1.50	1.14	1.7	25	0.20	−4±3	−$1.1±0.8	−$110,000±80,000
Sunshine:										
Nov. (x_{12})	198 hr.	29 hr.	0.035	0.074	0.2	70	0.03	------	------	------
Dec. (x_{13})	213 hr.	27 hr.	0.038	0.094	0.2	70	0.02	------	------	------
Jan. (x_{14})	228 hr.	40 hr.	0.173	0.047	13.2	1	0.65	7±2	$2.0±0.6	$200,000±60,000
Feb. (x_{15})	186 hr.	28 hr.	−0.182	0.093	3.8	10	0.36	−5±3	−$1.4±0.8	−$140,000±80,000

*The equation was $y=a_0+a_1x_1+a_1x^2_1+a_2x_2+ \ldots +a_{15}x_{15}$. The coefficients $a_2, \ldots, a_{15}$ are those shown above corresponding to $x_2, \ldots, x_{15}$. The values of the other coefficients were: $a_0=180.81$, $a_1=-0.74$, and $a_1'=0.09$, where x_1=time (1936/37=1, 1937/38=2, etc.). Additional data for this example: $R^2=0.99$, F ratio =32.1, significance level=0.05%, standard error of the estimate=6 lb., average butterfat yield per cow=267 lb.
**Based on butterfat production in the Puketaha herd testing group and climatic data for the Ruakura climatological station for the seasons 1936/37–59/60.

1959/60 indicated that such "wet" conditions occurred once in 6 years. The factory to farmer price of butterfat in November 1964 was $0.282 per lb.[1]; therefore, if this price is accepted as a measure or index of the value of butterfat production, it follows that an "increase" in butterfat production of 9±2 lb. per cow has a "value" of $2.6±0.6 per cow. Further, in order to assess the value, or economic significance in terms of agricultural income, of such an increase per cow in the butterfat production of the Waikato County, one may multiply the above value by the dairy cow population in that County. In 1961/62, this was 102,130; therefore, assuming that all dairy cows were affected in the same way—that is, an increase in the yield per cow of 9±2 lb., it follows that the "gain" in revenue from butterfat production for the whole County would be approximately $260,000±60,000. In the areas adjacent to the Waikato County, however, are over 0.5 million dairy cows; accordingly the "gain" in revenue from butterfat production would be in excess of $1 million ±300,000. In effect this can be considered as an approximate index of the effect on farm income from butterfat production in the Waikato area if "wet" conditions occur in October.

4. AGRICULTURAL FACTORS

In order that the effect on production and agricultural incomes could be assessed on a national basis a collation of the various partial correlations significant at the 2.5 percent level was made. For this purpose one example of each of the agricultural factors found to have a significant climatic factor associated with production is given in table 3. This allows a comparison to be made of the effect of a specific climatic variation on production and agricultural incomes where a significant correlation occurs between the climatic and agricultural factors. It is not possible to reduce all data to the same units, but it is possible to compare similar agricultural factors.

FIELD CROPS

A comparison of wheat, oats, barley, peas, and corn shows that the effect of a single significant specific climatic variation on yields is about 3 to 6 bushels per acre with a value ranging from $2 to $8 per acre. On the other hand, under similar conditions, potato production is subject to a variation of about 1 ton per acre valued at $80.

Specifically, four wheat partial correlations were significant, the effect of the specific climatic variations ranging from an "increase" of 5.7±1.1 bushels per acre in Southland County as a result of a "sunny" February, to a "decrease" of 2.5±0.9 bushels per acre in Manawatu County as a result of a "warm" October. The value of these fluctuations varied from $3.4±1.2 to $7.6±1.4 per acre. Similar variations in oat yields per acre as a result of the effects of significant climatic variations were found. In Waimea County, for example, a "cool" February was associated with an "increase" in the oat yield of 6.9±1.9 bushels, valued at $5.8±1.6 per acre. Barley yield variations from average as a "result" of a significant specific climatic variation were about 4 bushels per acre, four of the eight significant partial correlations being associated with "cool"

[1] All prices are in New Zealand dollars ($N.Z. 1.0=$U.S. 1.12), and are based on those ruling in November 1964.

TABLE 3.—*Effect on production and agricultural incomes* of significant** climatic factors: selected examples*

Agricultural factor	County	Month/season	Desired climate#	Effect of climatic variations##	
				Yield/unit	Value/unit ($ N.Z.)
Wheat	Southland	Jan	Cloudy†	5.3±1.1 bush/ac	$7.2±1.4/ac.
Oats	Levels	Dec	Cool	5.3±1.6 bush/ac	$4.4±1.4/ac.
Barley	Waimea	Dec	Cool	3.8±1.2 bush/ac	$3.4±1.0/ac.
Potatoes	Hawkes Bay	Dec	Sunny	1.14±0.42 tons/ac	$88±32/ac.
Peas	Springs	Nov	Dry	3.2±1.2 bush/ac	$1.8±0.6/ac.
Corn	Hobson	Nov	Cloudy	4.3±1.5 bush/ac	$7.0±2.4 /ac.
Butterfat	Waikato	Jan	Wet	10±2 lb/cow	$2.8±0.6/cow
Wool/sheep	Masterton	Previous autumn	Dry	0.3±0.1 lb/sheep	$0.14±0.04/sheep
Wool/acre	Hawkes Bay	Previous winter	Dry	1.3±0.4 lb/ac	$0.6±0.2/ac.
Meat/acre††	Ashburton	Previous summer	Wet	12±4 lb/ac	$2.0±0.6/ac.
Apples/tree	Vincent	Spring	Warm	0.5±0.2 bush/tree	$1.4±0.6/tree
Pears/tree††	Hawkes Bay	Summer	Wet	0.8±0.3 bush/tree	$3.2±1.4/tree

*Based mainly on 1964 prices, and 1961/62 agricultural data.
**At the 2.5 percent level.
#Relative climate associated with *above* average production.
##One standard deviation above or below average as relevant.
†Define as a month with a sunshine duration one standard deviation or more below the average. Similar definitions were used for the terms "warm," "sunny," "wet," "dry," and "cool."
††Significant at the 5 percent level.

conditions. The value of these variations in yield were about $4 per acre.

In the case of potatoes only one partial correlation was significant. With pea yields, however, there were several significant partial correlations. The variation in pea production per acre, as a result of a significant specific climatic variation was about 5 bushels per acre valued at nearly $4 per acre.

DAIRY PRODUCTION

The outstanding feature of the butterfat production analyses was the importance of relatively wet conditions in each of the 5 months October to February. Specifically, 12 of the 13 significant (at the 2.5 percent level) rainfall correlations were positive, a standard deviation increase in the average October, November, December, January, or February rainfall being associated with an "increase" in the butterfat yield of about 10 lb. per cow. The individual variations ranged from 8 ± 3 to 18 ± 5 lb. per cow and had an average value of about $3 per cow. The influence of relatively wet conditions, occurring on the average once in 5, 6, or 7 years (assuming a normal distribution of the rainfall data), on agricultural incomes from butterfat production is therefore emphasized. Conversely, the adverse effect of dry conditions occurring also on the average, say, once in 5, 6, or 7 years, is to "reduce" the income from butterfat by about $3 per cow. Other factors shown to be important for above average butterfat production were relatively cool and cloudy conditions, especially if these occurred early or late in the season. (For a review of the literature on climatic variations and dairy production in New Zealand, see Maunder [3].)

PASTORAL PRODUCTION

With pastoral production the analyses suggest that for wool production a specific climatic departure, where significant, is associated with a variation in average fleece weights of from 0.3 to 0.5 lb. per sheep valued at about $0.2 per sheep. For the two other pastoral factors assessed, that is to say, wool per acre and meat per acre, a similar significant climatic variation is generally associated with a variation of 1 to 3 lb. of wool per acre valued at about $0.6 to $1.0 per acre, and a variation of about 10 lb. of meat per acre to the value of about $2 per acre.

Specifically, for wool production per sheep, two partial correlations—both for Masterton County—were significant. In these cases a "dry" autumn and a "cool" winter were both associated with an "increase" in wool production of 0.3 ± 0.1 lb. per sheep. This variation in production was valued at $\$0.14 \pm 0.04$ per sheep. Two partial correlations, both for Hawkes Bay County, were also significant for wool production per acre. These indicated that a "wet" autumn and a "dry" winter were associated with an "increase" in wool production of about 2.0 lb. per acre valued at nearly $1 per acre.

PIP-FRUIT PRODUCTION

Three of the four aspects of pip-fruit production considered had significant partial correlations, the calculations suggesting that apple and pear production varies by about 0.5 to 1.0 bushels per tree as a "result" of a significant specific climatic variation. These variations in fruit production have a value of a little less than $2 per tree for apples and a little more than $2 per tree for pears.

5. ECONOMIC IMPORTANCE

An attempt to show the economic importance of the more significant agroclimatological associations in New Zealand is now made by comparing the partial correlations significant at the *one* percent level by areas and

TABLE 4.—*Economic effects of significant* agroclimatological associations***

Agricultural factor	County	Relative climate	Month/season	Effect of climatic variations#	
				Value/unit ($ N.Z.)	County value ($ N.Z.)
Wheat	Southland	Dry	Oct	$4.0±1.0/ac	$52,000±14,000
	Southland	Cloudy	Jan	$7.2±1.4/ac	$92,000±19,000
	Southland	Sunny	Feb	$7.6±1.4/ac	$100,000±19,000
Oats	Waimea	Cool	Feb	$5.8±1.6/ac	$400±120
	Marlborough	Cloudy	Nov	$3.4±0.8/ac	$1,300±200
	Marlborough	Warm	Jan	$1.8±0.6/ac	$680±200
	Marlborough	Cool	Feb	$2.0±0.6/ac	$840±260
	Levels	Cool	Dec	$4.4±1.4/ac	$2,500±800
Barley	Southland	Warm	Oct	$4.0±1.0/ac	$780±200
	Southland	Cool	Jan	$7.6±2.4/ac	$1,500±460
Butterfat+	Ohinemuri	Wet	Nov	$4.6±1.4/cow	$90,000±30,000
	Waikato	Wet	Oct	$2.6±0.6/cow	$260,000±60,000
	Waikato	Wet	Jan	$2.8±0.6/cow	$290,000±60,000
	Waikato	Sunny	Jan	$2.0±0.6/cow	$200,000±60,000
	Waikato	Wet	Feb	$2.6±0.2/cow	$250,000±12,000
	Masterton	Cloudy	Nov	$2.2±0.6/cow	$9,000±2,000
	Masterton	Wet	Dec	$2.8±0.8/cow	$10,000±3,000
	Masterton	Sunny	Jan	$5.6±1.2/cow	$23,000±4,000
	Masterton	Wet	Feb	$5.0±1.4/cow	$21,000±5,000
	Masterton	Cool	Feb	$3.4±0.8/cow	$14,000±3,000
Wool/acre	Hawkes Bay	Wet	Previous autumn	$1.0±0.2/ac	$790,000±160,000
Apples/tree	Waimea++	Wet	Summer	$1.4±0.2/tree	$470,000±90,000
Pear production	Waimea++	Cloudy	Previous winter		$36,000±10,000
	Waimea++	Dry	Summer		$42,000±10,000

*At the 1 percent level.
**Based mainly on 1964 prices, and 1961/62 agricultural data.
#Effect for month/season with relative climate as shown. All values are "credits." A similar "debit" would be associated with the "opposite" relative climate.
+Herd testing group data in county.
++Nelson and Mapua fruit district data in county.

agricultural factors. The "economic" effects of these significant agroclimatological associations are summarized in table 4.

AREA ANALYSIS

Only eight of the 27 counties analyzed had one or more partial correlations significant at the one percent level, and 21 of these 24 significant correlations were in five counties—Masterton (5), Southland (5), Waikato (4), Waimea (4), and Marlborough (3).

In Masterton County all five significant correlations were for butterfat production, the analysis suggesting that January sunshine, February rainfall, and February temperatures were the most significant climatic factors. Each of these factors "accounted for" over 55 percent of the variance in butterfat production in the area after the other factors (model I) had been allowed for. The effect of the significant climatic factors on butterfat production ranged from $2.2±0.6 per cow for a "cloudy" November, to $5.6±1.2 per cow for a "sunny" January. It is estimated that the "value" of these variations for the Masterton County were from $9,000±2,000 to $23,000±4,000.

Butterfat production was also closely associated with climatic variations in the Waikato County, the significant climatic factors in this case being associated with county income variations of over $200,000, the amount per cow being assessed at about $2.6 for a "wet" October, $2.8 for a "wet" January, and a "wet" February, and $2.0 for a "sunny" January. The importance of "wet" conditions in February was a particularly significant feature of the analysis, the squared partial correlation coefficient showing that over 90 percent of the variations in total annual butterfat production were "accounted for" by variations in the February rainfall.

In Waimea County, two of the four significant correlations were for pear production, a "cloudy" winter and a "dry" summer being associated with "increases" in pear production valued at $36,000±10,000 and $42,000±10,000 respectively, for the combined Nelson and Mapua Fruit Districts.

All three significant correlations for the Marlborough County were for oat production. The most significant of the three was November sunshine, a "cloudy" November being associated with an "increase" in oat yields valued at $3.4±0.8 per acre, compared with $1.8±0.6 for a "warm" January and $2.0±0.6 for a "cool" February.

In the other county, Southland, three of the five significant correlations were for wheat. In this case, the January and February sunshine variations each "accounted for" over 70 percent of the variations in the annual wheat production per acre.

AGRICULTURAL FACTORS

Of the 24 partial correlations significant at the one percent level, 10 were associated with butterfat production, five with oats, three with wheat, two with barley, two with pear production, and one with wool production per acre and apple production per tree. The wheat and butterfat associations are now examined from a broad economic viewpoint.

Wheat.—The three significant wheat correlations were all for the Southland County. Accordingly, a comparison of the economic implications of significant climatic variations on wheat production per acre in Southland County can be made. Table 4 shows that of the three significant factors involved, a "sunny" February was associated with wheat yield variations valued at $\$100{,}000 \pm 19{,}000$ for the County, compared with $\$92{,}000 \pm 19{,}000$ for the association with a "cloudy" January, and $\$52{,}000 \pm 14{,}000$ with a "dry" October. It is therefore suggested that a "sunny" February, associated with an increase in the wheat income of the Southland County of $\$100{,}000 \pm 19{,}000$, has twice the "economic effect" of a similar significant climatic variation ("dry" conditions) in October.

Butterfat.—The major feature of the analysis, however, is found to be the significance of climatic factors in their influence on butterfat production. Indeed 10 of the 24 partial correlations significant at the one percent level were for butterfat production. Considering all 10 correlations, including four for Waikato County and five for Masterton County, the effect of a significant standard deviation departure from the average varied from $2.2 to $5.6 per cow.

The value of these variations per cow when related to particular areas fluctuates considerably, and depends (in this case) on the number of dairy cows in milk. This is clearly demonstrated when Waikato is compared with Masterton. In Waikato County the "county value" of the variations in butterfat production as discussed above were over $200,000, whereas in Masterton the equivalent "county value" was in the range $9,000–$23,000. These values are of course only an index of the total value of the variations in butterfat production in the two areas. In the case of the Waikato County, for example, a more realistic estimate of the total effect of a significant specific climatic variation on butterfat production, and the subsequent variations in the income from butterfat, can be obtained by assessing the number of dairy cows in milk located in the Waikato County and surrounding areas. A first approximation of this could be taken as the dairy cow population of the South Auckland Land District which in recent years has totalled over 750,000. (This represents nearly 40 percent of all dairy cows in New Zealand.) Accordingly, if the "values per cow" in the Waikato County are taken as an index of the variations in butterfat income per cow for the South Auckland area, it can be suggested that a significant climatic variation such as a "wet" January is "worth" about $2 million to the area (750,000 cows $\times$ $2.6 per cow).

Based on the period 1936/37–1959/60 the probability of a "wet" January (the significant month discussed above) is one in six, compared with a probability of one in eight for a "dry" January. The analysis therefore indicates that if the climate at the Ruakura climatological station is taken to be representative of the climate of South Auckland, then once in about six seasons a "wet" January will be associated with an "increase" of about $2 million in the income of dairy farmers of South Auckland. Conversely, it might be expected that a comparable "fall" in income would occur once in about eight seasons as a "result" of a "dry" January. These substantial variations in income thus provide a measure of the potential economic importance of significant climatic departures from the mean, as they affect butterfat production in South Auckland—New Zealand's premier dairying area.

6. CONCLUSIONS

On a world scale climatic variations in New Zealand are relatively small and the country is generally favored with "good" growing conditions. It is clear, however, from the above analyses, that significant variations do take place, and it is equally clear that the effect of such variations, in a country where over 90 percent of the foreign exchange comes from the sale of agricultural produce, is of fundamental economic concern. The limitations of the type of analysis used are fully appreciated, and it is clear that much more research must be done before the quantitative assessments discussed can be put to more practical use. Nevertheless, this paper has shown that, in some areas of New Zealand, it is possible to measure both the probability of occurrence *and* the effects on farming income of significant climatic variations as these in turn affect agricultural production.

It is envisaged that similar investigations, not however confined to agriculture, could be developed for certain regions of the United States and Canada. If several pilot schemes were made, the overall results could lead to the formulation of what one could call an "econoclimatic model" in which the effect of climatic variations on the total economy could be assessed.

ACKNOWLEDGMENT

The project was assisted financially by a grant from the University Grants Committee (New Zealand).

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[*Received April 17, 1967: revised September 18, 1967*]